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Bethesda, Md. 20084

DEPARTMENT OF THE NAVY DTNSRDC

PREDICTED SMOOTH WATER PERFORMANCE OF SEVERAL PARTIAL HYDROFOIL SUPPORTED LVA CONFIGURATIONS

by

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SHIP PERFORMANCE DEPARTMENT

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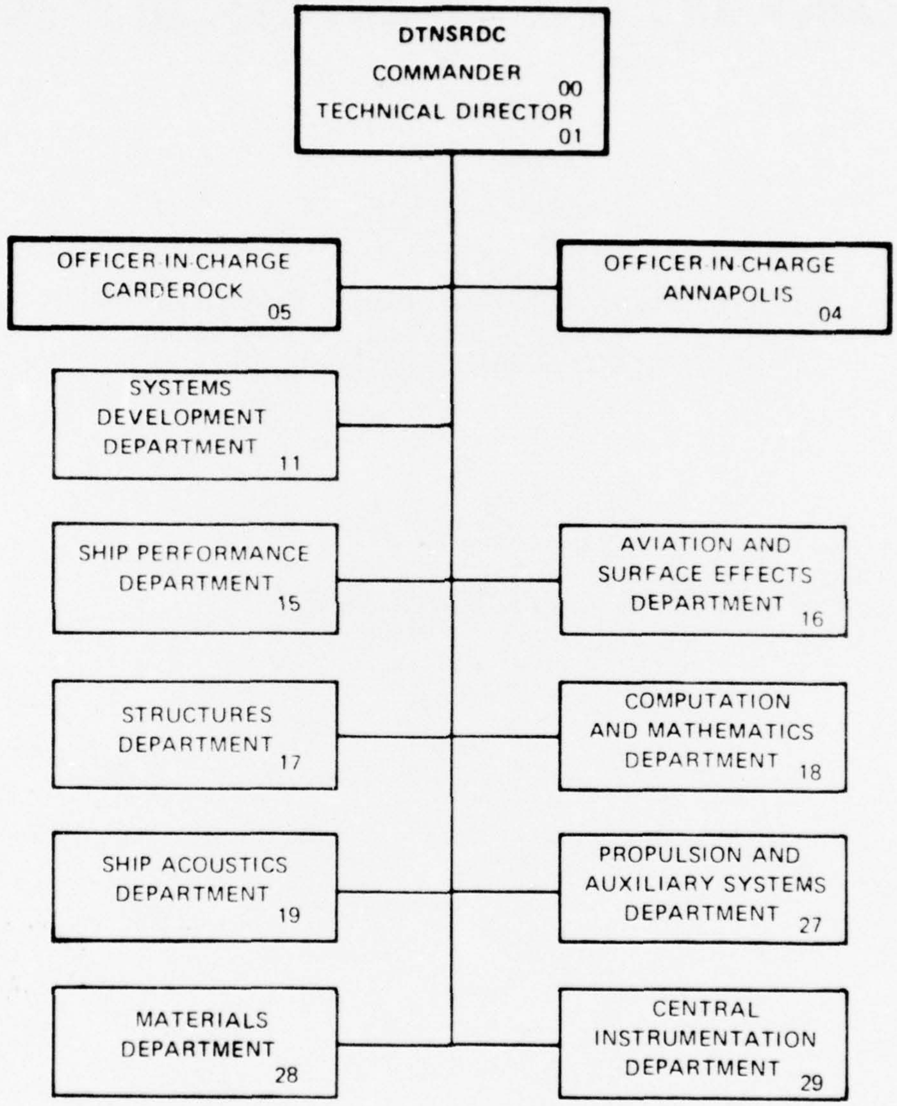

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The smooth water performance of several partial hydrofoil supported LVA (Landing Vehicle Assault) planing craft configurations is predicted and compared to the predicted resistance of configurations without foils. A smooth water resistance prediction method is developed which accounts for the forces produced by a flapped planing surface. Foils are selected for the LVA and then foil weights are estimated. The results show that the foils can be used to reduce the hump drag by 2,300 lb at a 1,000 lb NEXT Page

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ABSTRACT

The smooth water performance of several partial hydrofoil supported LVA (Landing Vehicle Assault) planing craft configurations is predicted and compared to the predicted resistance of configurations without foils. A smooth water resistance prediction method is developed which accounts for the forces produced by the foil as well as the forces produced by a flapped planing surface. Foils are selected for the LVA and then foil weights are estimated. The results show that the foils can be used to reduce the hump drag by 2,300 lb at a 1,000 lb additional drag penalty at high speed or they can be used to produce marginally better high speed performance at about the same hump drag.

INTRODUCTION

This report provides the LVA (Landing Vehicle Assault) program office with quantitative smooth water resistance predictions which show the anticipated performance gain due to the addition of partial hydrofoil support to the DTNSRDC-P1 LVA planing craft conceptual design. The work entailed the synthesis of a smooth water partial hydrofoil resistance prediction method using recent planing hull technology in order to take into account the effect of the transom flap as well as the effect of the foil. The planing hull portion of the prediction method was then compared with DTNSRDC-P1 model data. In addition to the assembly of a prediction method, three foils used in different configuration were selected and sized and foil weight estimates were made. The predicted resistance in the 10-40 knot speed range of several foil and transom flap LVA configurations is compared to flap only LVA configurations.

Description of the Partial Hydrofoil Supported LVA

A sketch of the partial hydrofoil supported LVA is shown in Figure 1. The hull is the DTNSRDC-P1 designed by the LVA program office. The w shaped forward portion of the hull has a -10° deadrise which tapers to 0° at the transom flap hinge line. The hull is equipped with one of two controllable transom flaps, a full span 11 ft by 3 ft flap or a partial span 6.5 ft by 3 ft flap. The partial hydrofoil supported LVA consists of the basic hull mentioned above with or without one of the two flaps and with one of three controllable incidence angle Tee foils.

Foil Selection and Description

Foils similar to the PGH-2 forward foils were selected because the PGH-2 forward foils met the following criteria:

a) Acceptable and known performance in the 35-40 knot speed range

b) Foils and struts are structurally adequate

c) Foil and strut are in a Tee shaped configuration.

The strut is mounted at the centerline of the craft. (A side mounted strut can have excessive drag due to a hull induced transverse flow component. Strut alignment with the flow may not be possible for all craft speeds. It is assumed that there is no transverse flow at the centerline while the craft is moving straight ahead.)

Foil sizing was subject to the following constraints:

1) A foil which retracted between the tracks was limited in span to 7.3 ft, the approximate distance between the inside edges of the tracks. (Track configuration is not yet firmly fixed).

2) A foil should not produce a lift of more than 40% of the craft weight when operating at maximum craft speed and optimum foil lift-drag ratio. The 40% criteria was borrowed from reference 1 which indicated that for the partial hydrofoil supported version of DTNSRDC model 5184, porpoising occurred at values of foil lift higher than 40% of the craft weight.

The geometry of the three selected configurations is shown in Figure 2. Foil I fits between the tracks while Foil II, due to its 10.08 ft span, has to be mounted at the transom behind the tracks.

At 40 knots and optimum lift-drag ratio, Foils I, II and III support 17.0, 39.2, and 30.0% of the LVA weight. It is not feasible to fit a large foil under the hull which will support 40% of the craft weight and still maintain good foil performance and the foil retraction capability.

Foil Weight Estimate and Structural Considerations

The LVA with partial hydrofoil support will be heavier than the nonhydrofoil supported version due to the weight of the foil, the strut, the foil retraction system, local hull strengthening in way of the foil and the foil incidence angle or flap control system. The weight of these components can only be calculated accurately after the design and all the dimensions are finalized.

The estimated weight of the three different foil strut-pod combinations that were examined for possible LVA use are presented in Figure 2. Configurations I and II foils are different size geosyms of the PGH-2 forward foil and the configuration III foil is a scaled down PGH forward foil with a different aspect ratio. Weight estimates for the I and II foil-strut-pod assemblies were made by assuming that the weight varies with the enclosed volume of the foil, strut and pod. The weight of foil assembly III was derived from the weight of foil assembly I by assuming that the weight is scaled by a factor of $(7.3/5.0)^2$, the ratio of the aspect ratio's squared. Note that the span of both foils is 7.3 ft, a limitation imposed by the distance between the LVA tracks.

It should be noted that the weight estimate for the configurations I and II foils is very reasonable from a structural point of view because the stress in the foils scales with the loading not with the size. The PGH-2 forward foil did not fail so its scale geosym shouldn't fail either. By the same reasoning the strut should be structurally adequate, however, the weight of the scaled down hollow LVA strut may be higher than indicated in Figure 2 if the smaller LVA strut cannot be fabricated with the same techniques and scaled down dimensions as the full size.

The configuration III foil is structurally more conservative than either the I or II foil due to its greater thickness and chord at the root. According to simple beam theory with an assumed point load proportional to the foil area and located at the average chord, the root stress of foil III can be compared to that of foil I by the following equation:

$$\sigma_{III} = ({}^{t}I/t_{III})^2 \, \sigma_I = 0.47 \, \sigma_I$$

where σ is the root stress, t is the root thickness and the subscripts I and III denote the foil configuration number. Since the stress in Foil III is only 47% that of foil I, a structural design change should result in a foil system weight less than the 656 lb shown in Figure 2.

An estimate of the foil retraction system weight, incidence or flap control weight and the weight of necessary local hull strengthening is not within the scope of this report and probably could not be made accurately at this early design stage. Instead of neglecting the weights of the above components, it is assumed that the foil supported LVA weighs 1,000 lb more than the nominal 55,000 lb weight of the nonfoil supported LVA. Note that the 276 lb foil and overweight 656 lb foil fit between the tracks and are anticipated to be used in conjunction with a trim flap while the 714 lb foil is used instead of a trim flap. Therefore, in the case of the 714 lb foil the nominal 1,000 lb additional weight for foil supported concepts includes the foil weight plus other weights minus the weight of a trim flap.

Smooth Water Partial Hydrofoil Supported LVA Resistance Prediction Methods

The smooth water partial hydrofoil supported planing craft resistance prediction method of reference (1) was examined for suitablility to the LVA performance prediction and was discarded because it had no provision for the use of trim flaps and because it has poor correlation with model resistance at hump. Instead, a new performance prediction method based on the Shufford-Brown equations (Reference 2) for lift, drag, and pitching moment of a prismatic planing surface equipped with transom flaps was developed. These equations are combined with the predicted lift, drag, and moment of

the foil and strut and are solved for the static equilibrium trim and equilibrium drag of the craft. Then, in order to obtain a better prediction at hump, the equilibrium drag was multiplied by the drag correction factor of reference 3.

There are two configurational differences between the LVA-P1 and the hypothetical planing craft for which the Shufford-Brown equations were derived. They are: 1) the LVA flaps are mounted under the transom instead of hinged at the transom and 2) the LVA has a shallow w shaped hull tapering to zero deadrise at the transom instead of a prismatic planing hull with constant deadrise in the range of 0° to 50°. In order to account for these differences, an "effective LCG" value, a zero degree deadrise and a calculated 3% increase in wetted surface was used with the Shufford-Brown equations and in the calculation of the hump drag correction factor. The "effective LCG" is defined as the distance between the flap hinge line and the LCG.

The Shufford-Brown equations assume that the craft is infinitely long and, as a consequence, at high speed and low trim angles the predicted wetted keel lengths can be in excess of the craft length. Generally as the speed increases, and trim decreases the predicted wetted keel length increases. For the LVA resistance predictions, a maximum allowable wetted keel length of 26 ft was assumed. A short vertical bar at the high speed end of a predicted resistance curve indicates that a 26 ft wetted keel length has been reached.

The experiments on which the Shufford-Brown equations are based investigated the prismatic planing hull performance for flap angles up to 15° and flap chords up to 20% of the craft beam. The validity of the equations when applied to larger flaps and flap deflections is not known. For the LVA performance predictions, the equations were assumed valid for flap chords up to 27% of the craft beam and flap deflections up to 20°.

It is the author's opinion that this extrapolation of the flap chord/beam ratio to 27% and flap angle to 20° is reasonable for use with the LVA. It is recognized that increasing the flap size and angle increases the flap drag and that there must be a minimum point beyond which an increase in flap angle will not be offset by a corresponding larger decrease in hull drag. Compared to conventional craft, the LVA is very heavily loaded and because of this heavy loading it is expected that the hump drag is primarily caused by the hull and not the flaps. It is felt that in the case of the LVA, minimum hump drag will occur at a larger flap angle than in the case of a lightly loaded craft, and therefore calculations were performed for 20° flap angles. The extrapolation to 27% flap chord to transom width ratio was done because of the specified 3 ft transom flap width.

All the resistance predictions apply to a "bare hull" LVA. The drag of rudders, propeller shafts, struts, bossings or other appendages are not calculated. The hull is assumed to be smooth and the resistance of possible gaps, or overlaps caused by improperly fitting track covers is not accounted for. In addition, it is assumed that the track covers are watertight.

Three different Tee shaped foil-strut combinations, two geosyms with aspect ratio 7.3 and third with same foil section shape but aspect ratio 5, were considered for the LVA. The performance of the 7.3 aspect ratio foils operating at foil depth to average chord ratios greater than or equal to 2.0 are presented in Figure 3 which is a polynomial curve fit to experimental data. The performance of the aspect ratio 5 foil was also obtained from Figure 4 by applying the equations of Reference 4, p. 8 which predict the performance of a given aspect ratio foil from the known performance of a foil with the same section shape but of differenct aspect ratio. When any of the three foils were operating at foil depth to average chord ratios between 0.5 and 2.0, the experimentally derived lift and drag correction multipliers shown in Figure 4 for foils operating near the free surface were applied.

The incidence angle of the foils is controllable while the craft is underway. At present, it is assumed that the foil incidence angle is controlled by pivoting the whole foil and strut

assembly, however, the predictions for foil performance are expected also to apply to a foil that is pivoted about the bottom of the strut and to a lesser degree to a flapped foil. Foil incidence angle is defined as the angle between the foil nose tail line and the undisturbed water surface and is shown in Figure 5 along with the flap angle and trim angle.

Since the foil prediction is based on experimental results using a highly polished metal foil, the prediction applies only to clean, smooth, and polished full scale foils. This could correspond to the LVA in a "just-launched" condition transiting to a beach for the first time. Any damage to the foil surface incurred during overland operations or fouling of the foils due to a long time foil immersion is not accounted for. In addition, fouling of the planing hull is also not taken into account. In the normal LVA operation, fouling is not expected.

The performance prediction does not take into account any interference drag or interference effects between the foil and the hull. For small foil incidence angles, small values of foil lift, and for foils located 2 average chords or more below the hull, the interference effects are expected to be small. Interference effects are expected to be significant when the foil downwash is strong enough to change the pressure distribution under the hull and thus affect the trim of the craft.

Comparison of Bare Hull Smooth Water Predicted Performance With Model Data

In order to help ascertain the accuracy of the partial hydrofoil supported LVA prediction method, a few resistance predictions were made for the non foil supported LVA and were compared to model resistance obtained at Stevens Institute of Technology (Reference 5). The smooth water bare hull predicted and measured resistance and trim for the LVA-P1 without foil or trim flap is shown in Figure 6 and in Figures 7 and 8 for the LVA equipped with a partial span trim flap. In addition, the predicted and measured smooth water resistance and trim of NSRDC model 5032 is shown in Figure 9. DTNSRDC model 5032 is similar to the LVA in that it has a blunt bow, a flat bottom, and a length beam ratio which is only slightly higher than that of the LVA. The loading of model 5032 is only half that of the LVA and therefore its performance could roughly represent the performance of the hull of a 50% foil supported LVA.

Examination of Figure 6 through 8 shows that the prediciton method over predicts the LVA pre hump 10 knot drag and trim of the hull and underpredicts the drag and trim at speeds above 20 knots. It is expected that these trends would hold true for the performance prediction of a partial hydrofoil supported LVA.

Comparison of LVA Predicted Smooth Water Resistance for Configurations With and Without foil Support

Smooth water resistance predictions for the bare hull, partial span flap and full span flap, 55,000 lb, LVA shown in Figures 10, 11 and 12 were calculated in order to provide base line performance levels for comparison with the foil supported LVA configurations. These predictions show an expected decrease in hump drag and hump trim due to an increase in flap size and flap deflection. The difference in the high speed resistance of the partial and full span flap configuration operating at slightly different flap angles is negligibly small. The trim angles at hump are large compared to that of a conventional planing hull.

As mentioned before, the performance prediction equations are derived from experimental data on prismatic planing hulls with transom flaps deflected at angles up to 15°. In this report, these equations are assumed to hold for transom flap deflection up to 20°. The prediction for a 25° flap deflection shown in a dashed line on Figure 12 is included as a matter of academic interest and should be relied upon only if in the future the performance equations are shown to be valid for flap angles up to 25°.

A near minimum predicted resistance for several partial hydrofoil supported LVA configurations with controllable foil angle of attack and controllable transom flap angles were generated by calculating the resistance at various combinations of foil incidence angle and transom flap angle. For each 2 knot speed increment from

10 to 40 knots the resistance was calculated for 0, 3, 6, 9, 12 and 15° foil incidence angles and 0, 5, 10, 15, and 20° transom flap angles. In order to fill in missing minimum points, calculations were also done at 0, 1, 2, 3, 4, 5, and 7.5 degree foil incidence, and transom flap angles for 15, 30, 35 and 40 knot speeds. The minimum resistance from the above matrix was then plotted as shown in Figures 13 and 14 for configurations I and II partial hydrofoil supported LVA with foils located 6.5, 12.5 and 18.5 ft. forward of the transom.

The foil incidence angle, hull trim angle, transom flap angle, LVA resistance weight ratios and foil lift to LVA weight ratios are shown in Figure 15 for the configurations I and II partial hydrofoil supported LVA operating at hump and at high speed. Note that the minimum hump resistance for all the configurations shown occurred for the 20° transom flap deflection and for the 6.5 and 12.5 ft foil location configurations it occurred at the maximum 15° foil incidence angle. These transom flap deflection and foil incidence angles produced the lowest trim angles. At the 18.5 ft foil location the minimum hump drag was obtained at 6° incidence angle for foil I and 3° incidence angle for foil III. These results indicate that minimum hump drag occurs when the foil and transom flap angles are set to produce lift and a large bow down moment and a consequent decrease in hull trim angle.

The predicted resistance and trim of the LVA with foil configuration II located at the transom is shown in Figure 16. Foil III replaces the transom flap and it is not as effective as the full span transom flap in reducing drag throughout the speed range. Resistance predictions for an LVA with foil III at the transom were also made. The LVA with foil III results are not shown since the drag was always higher than the drag of the LVA with foil II.

A summary graph of the lowest predicted hump resistance LVA configurations with transom flap only, foil only and foil and flap is presented in Figure 17 along with the predicted resistance of the partial flap LVA for which there is model data available (See Figure 7). The configuration with the full span transom flap with foil III located 6.5 ft. forward of the transom has the least hump resistance of all the configurations examined. Both the full span transom flap only configuration and the foil II at transom configuration have a hump drag which is at least 2000 lbs higher than that of the foil II configuration with the full span transom flap. The high speed resistance between 32 and 40 knots is about the same for the partial and full span transom flap configurations.

CONCLUSIONS

1) The hump drag of all the configurations examined is decreased with trim angle. The LVA with foil III located 6.5 ft. forward of the transom and with the full span transom flap showed the lowest predicted hump drag (11,100 lbs) and the lowest predicted trim (11.75°). As shown, a foil located aft of the center of gravity and a full span transom flap can be used to decrease the trim angle and drag at hump.

2) The predicted high speed 35 knot smooth water drag of the following 4 configurations is between 8,318 and 9,442 lbs.

a) LVA with foil I at 18.5 ft. forward of transom and with the full span transom flap

b) LVA with foil III at 18.5 ft. forward of the transom and with full span transom flap

c) LVA with full span transom flap

d) LVA with partial span transom flap

3) About the same reduction in hump drag was acheived with foil II located at the transom as with the full span transom flap, but the 30 knot resistance of the foil II configuration was 2,700 lbs higher and the 40 knot resistance was 1,700 lbs higher than the full transom flap configuration resistance.

RECOMMENDATIONS

1) Conduct an experimental program to determine the smooth water performance of the LVA with several large transom flaps (chord-beam ratio up to 1/2) set at progressively larger and larger flap angles until the hump drag is minimized.

2) Check the validity of the performance equations of Reference 1 at transom flap angles greater than 15°.

3) Investigate the LVA performance with cambered or double hinged transom flaps. Determine how much of this work could be done theoretically and how much would have to be done experimentally.

4) Investigate the rough water performance of the partial hydrofoil supported LVA which uses foil III and full transom flap.

5) Examine the possibility of moving the LCG further forward in order to reduce the hump trim and hump drag.

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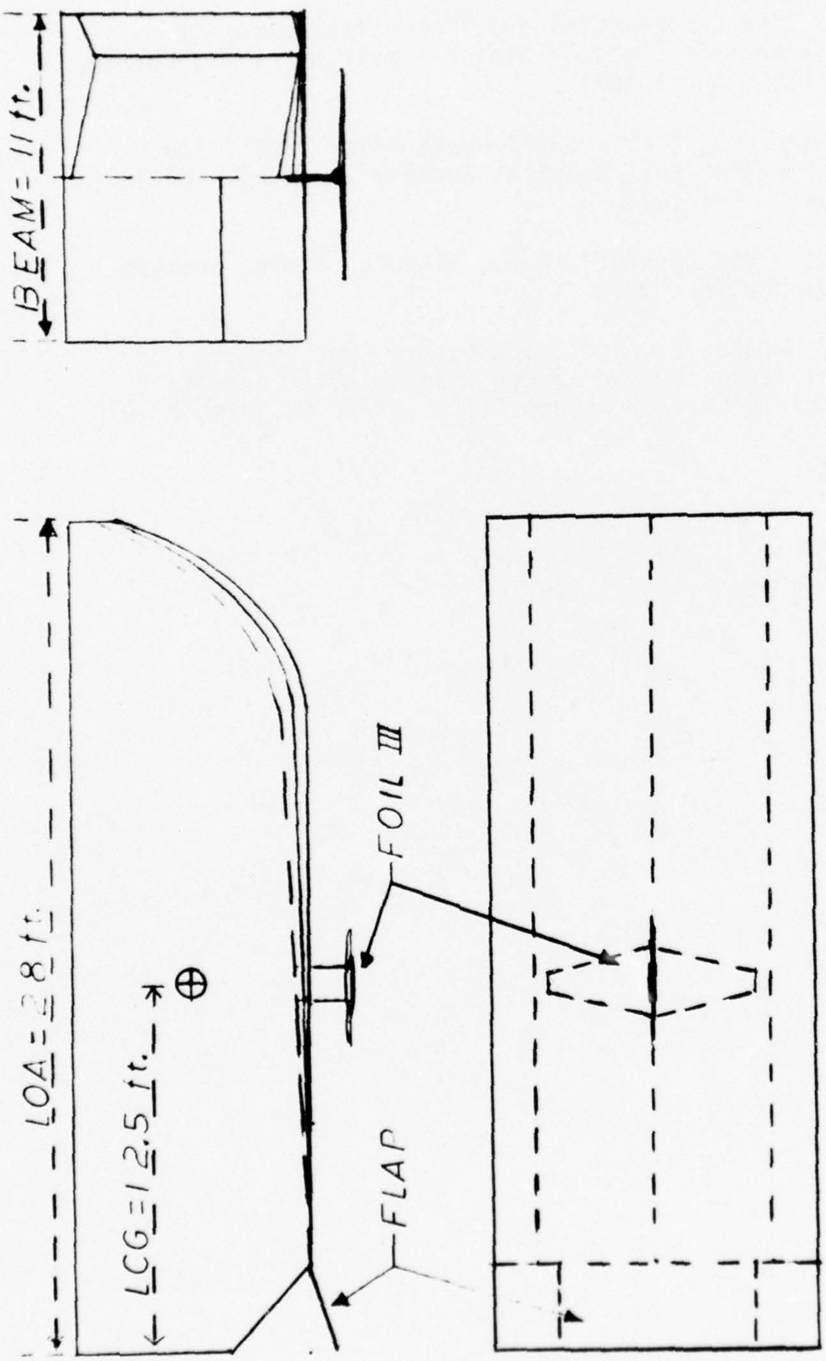


Figure 1 - Sketch of partial hydrofoil supported LVA

	PGH-2 Foil-Strut Pod Assembly (Weights from Reference)	POSSIBLE LVA FOILS (Weights are estimated)		
		Configuration I	Configuration II	Configuration III
STRUT				
Section	NACA 61-012	NACA 16-012	NACA 16-012	NACA 16-012
Chord	3.0 ft (.91 m)	1.35 ft (.411 m)	1.86 ft (.566 m)	1.97 ft (0.6 m)
Material	Aluminum	Aluminum	Aluminum	Aluminum
Weight	1452 lb (6458 N)	133 lb (591 N)	348 lb (1547 N)	282 lb (1254 N)
POD				
Length	6.5 ft (1.98 m)	2.92 ft (.89 m)	4.02 ft (1.22 m)	4.26 ft (1.30 m)
Weight	69 lb (307 N)	7 lb (31 N)	16 lb (71 N)	19.4 lb (86 N)
FOIL				
Section	NACA 16-306	NACA 16-306	NACA 16-306	NACA 16-306
Span	16.21 ft (4.94 m)	7.3 ft (2.22 m)	10.07 ft (3.07 m)	7.3 ft (2.22 m)
Mean Chord	2.22 ft (.676 m)	1.0 ft (.304 m)	1.38 ft (.42 m)	1.46 ft (445 m)
Root Chord	3.61 ft (1.10 m)	1.62 ft (.493 m)	2.23 ft (.679 m)	2.36 ft (.719 m)
Tip Chord	0.83 ft (.252 m)	.373 ft (.113 m)	.51 ft (.155 m)	.54 ft (.164 m)
Aspect Ratio	7.3	7.3	7.3	5.0
Material	17-4 PH	17-4 PH	17-4 PH	17-4 PH
Weight	1858 lb (8264 N)	170 lb (756 N)	446 lb (1983 N)	361 lb (1605 N)
TOTAL WEIGHT	2973 lb (13223 N)	270 lb (1200 N)	714 lb (3175 N)	656 lb* (2917 N)*

*Conservative weight estimate as explained in text

Figure 2 - Estimated Weight and Geometry of LVA Hydrofoil Candidates

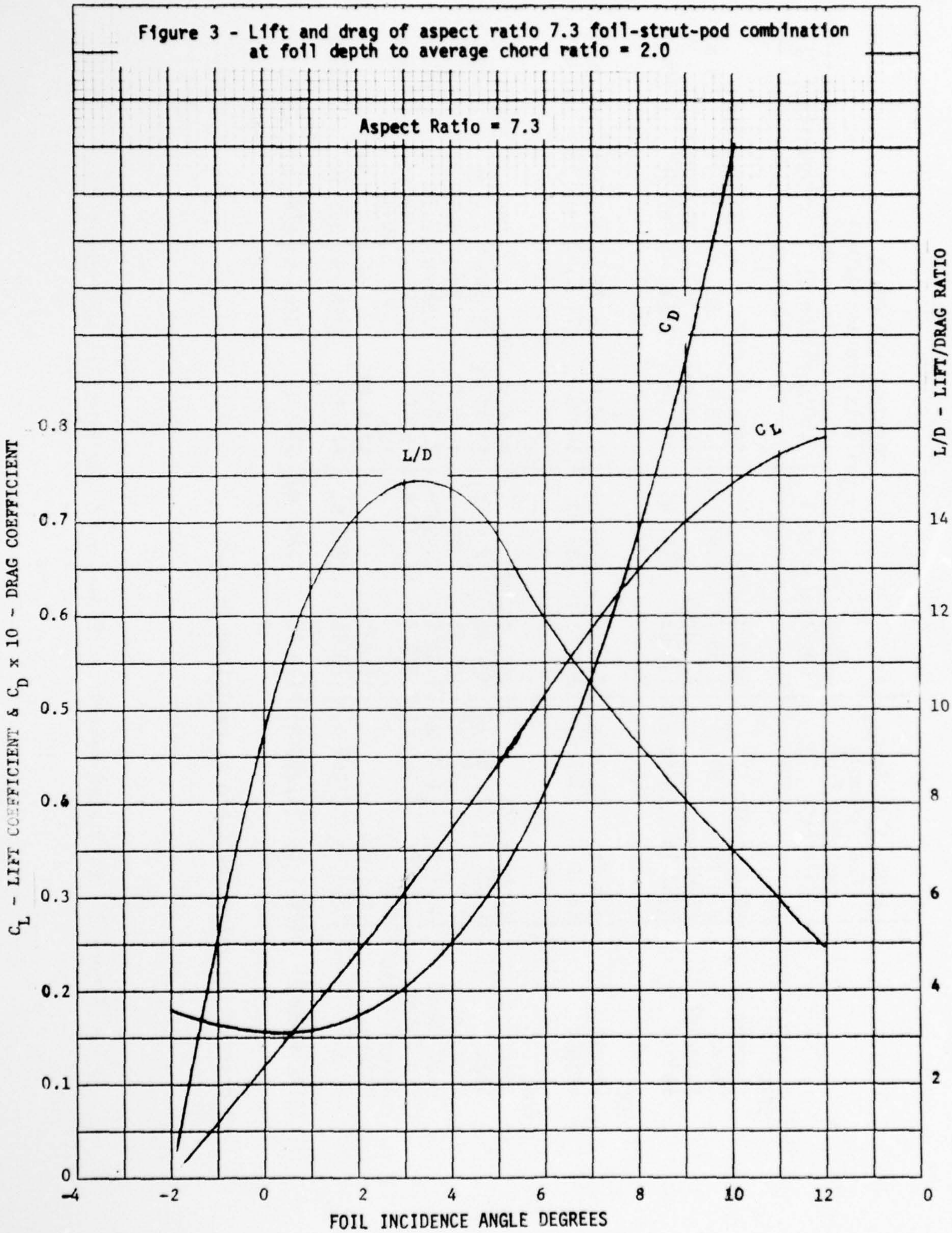


Figure 3 - Lift and drag of aspect ratio 7.3 foil-strut-pod combination at foil depth to average chord ratio = 2.0
Aspect Ratio = 7.3
C_D
C_L
L/D
C_L - LIFT COEFFICIENT & C_D x 10 - DRAG COEFFICIENT
L/D - LIFT/DRAG RATIO
FOIL INCIDENCE ANGLE DEGREES
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14
12
10
8
6
4
2
0
-4
-2
2
4
6
8
10
12

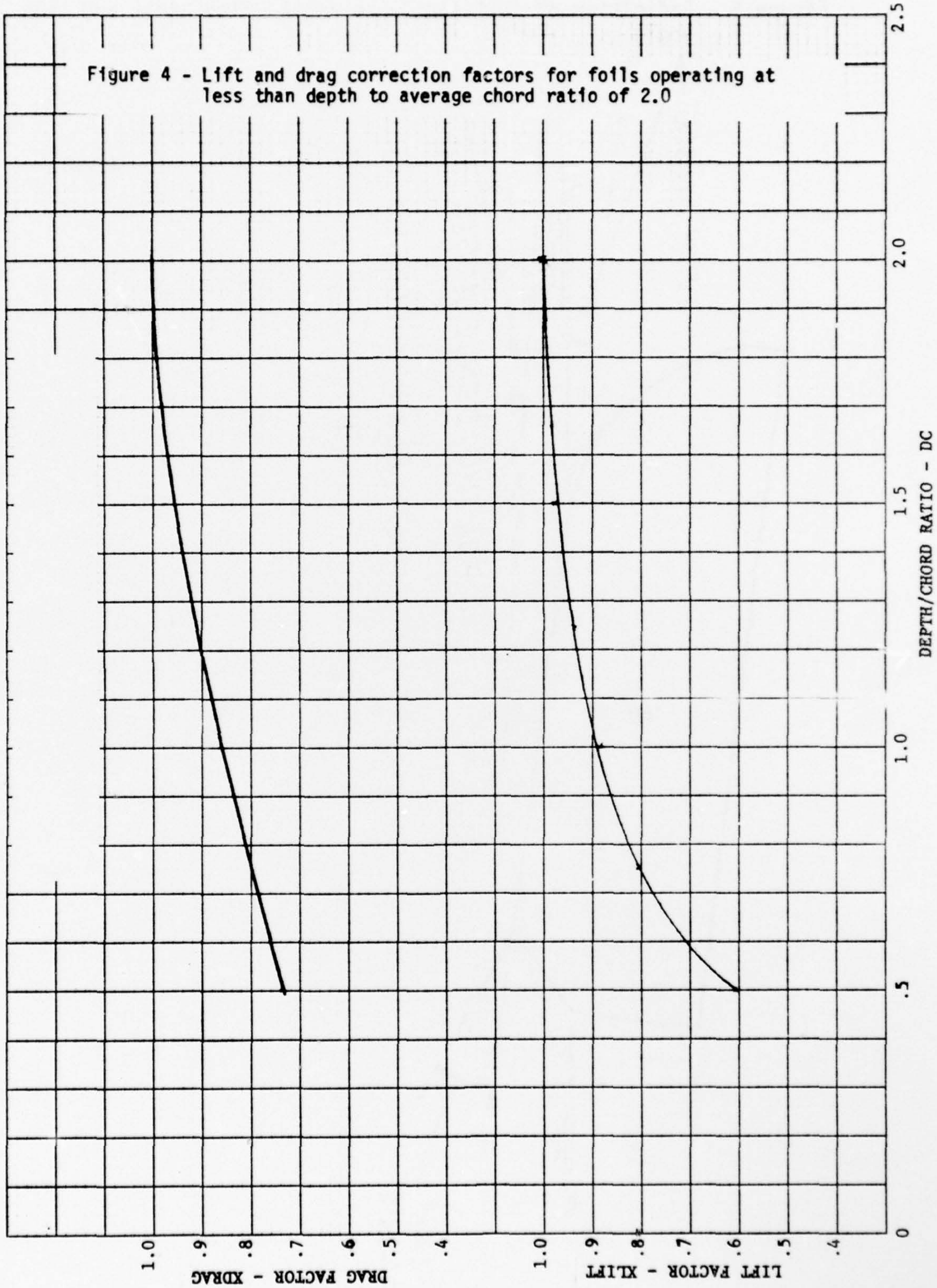
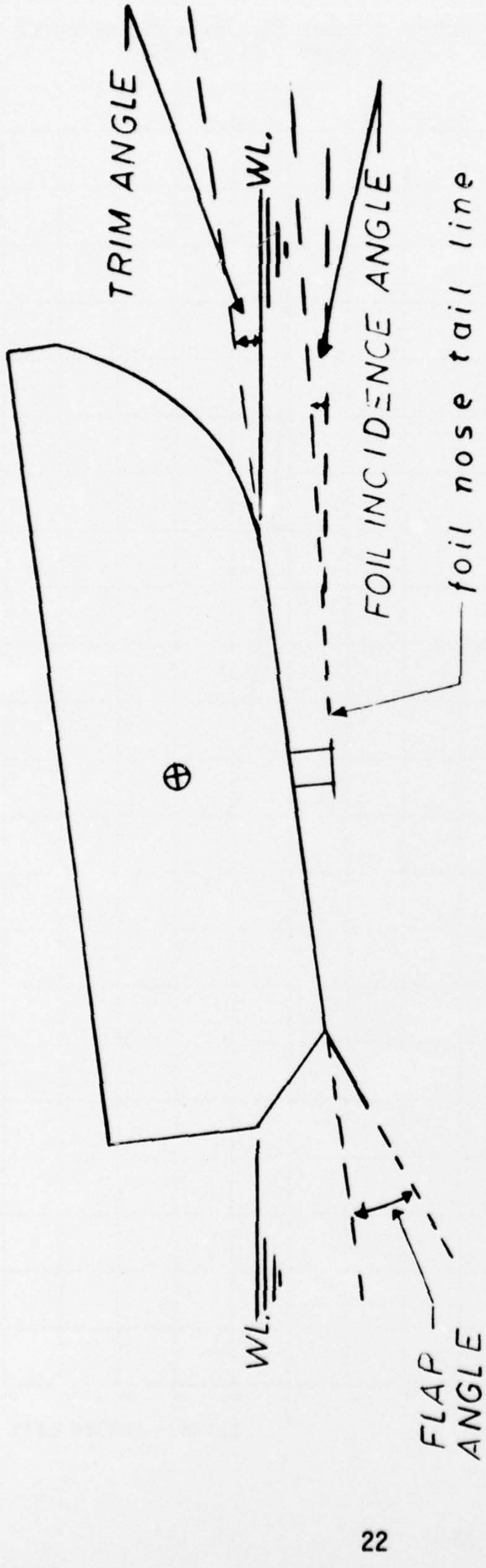


Figure 4 - Lift and drag correction factors for foils operating at less than depth to average chord ratio of 2.0

Figure 5 - Definition of foil incidence angle, flap angle and trim angle



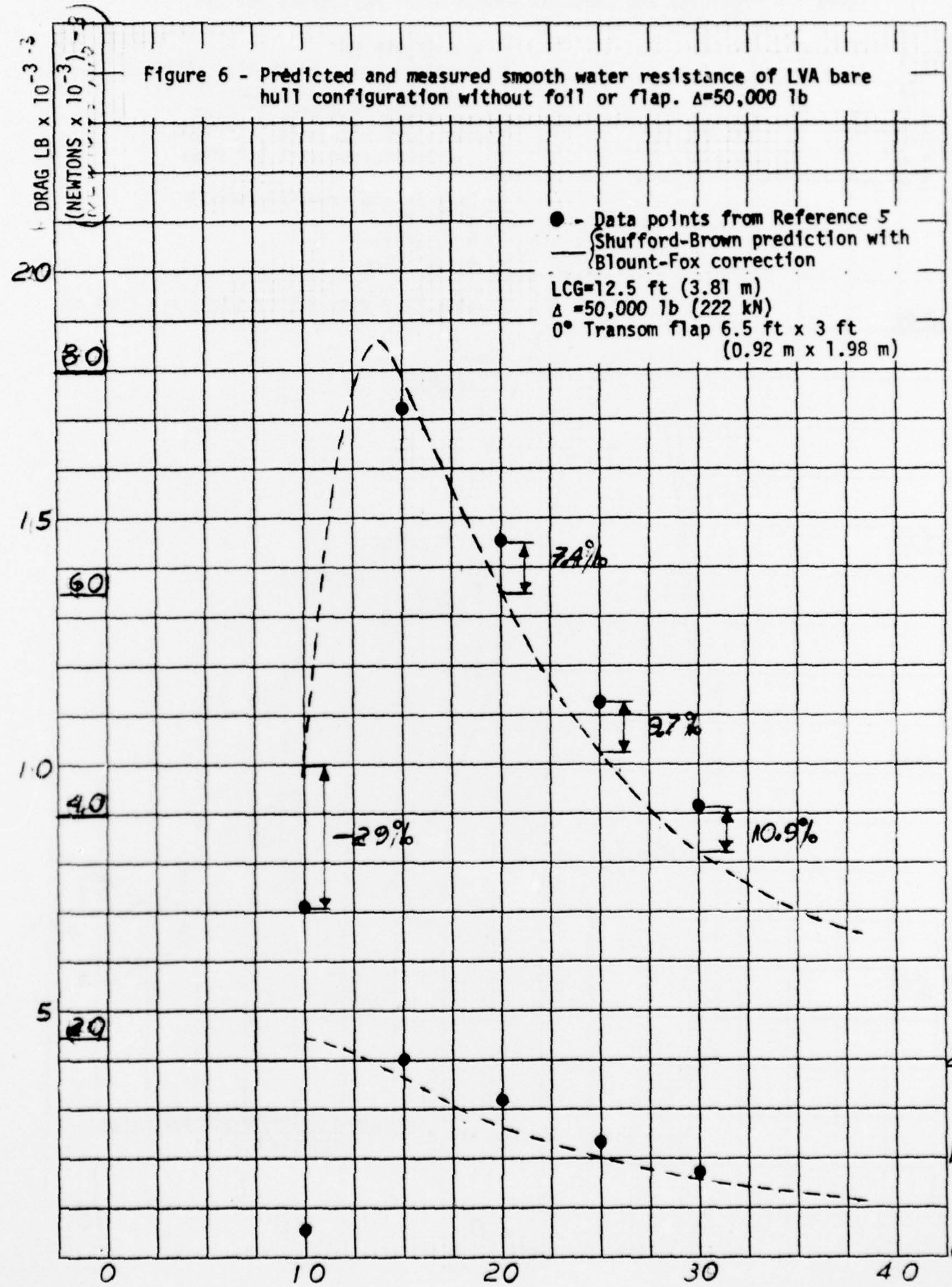


Figure 6 - Predicted and measured smooth water resistance of LVA bare hull configuration without foil or flap. Δ=50,000 lb

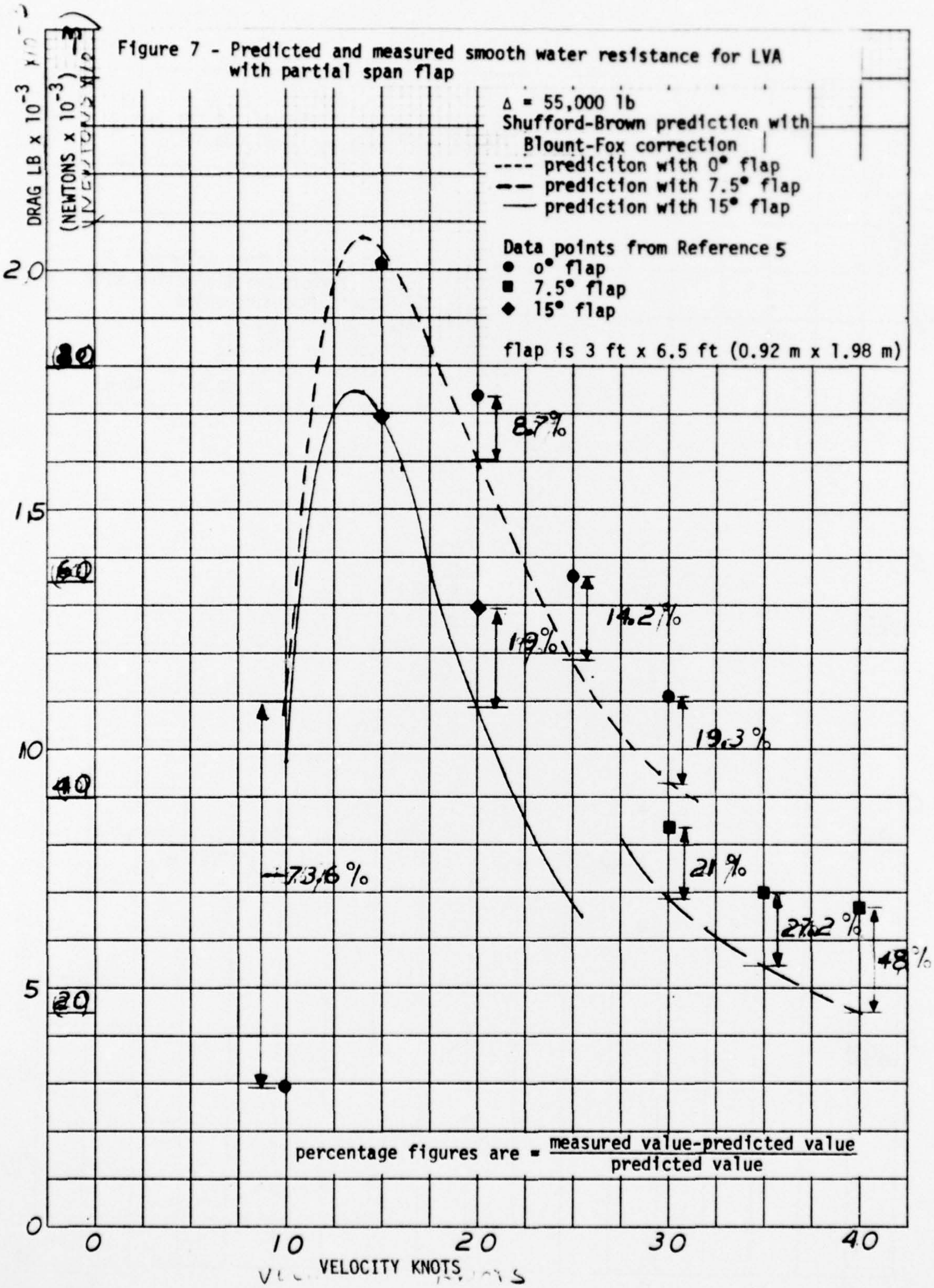


Figure 7 - Predicted and measured smooth water resistance for LVA with partial span flap

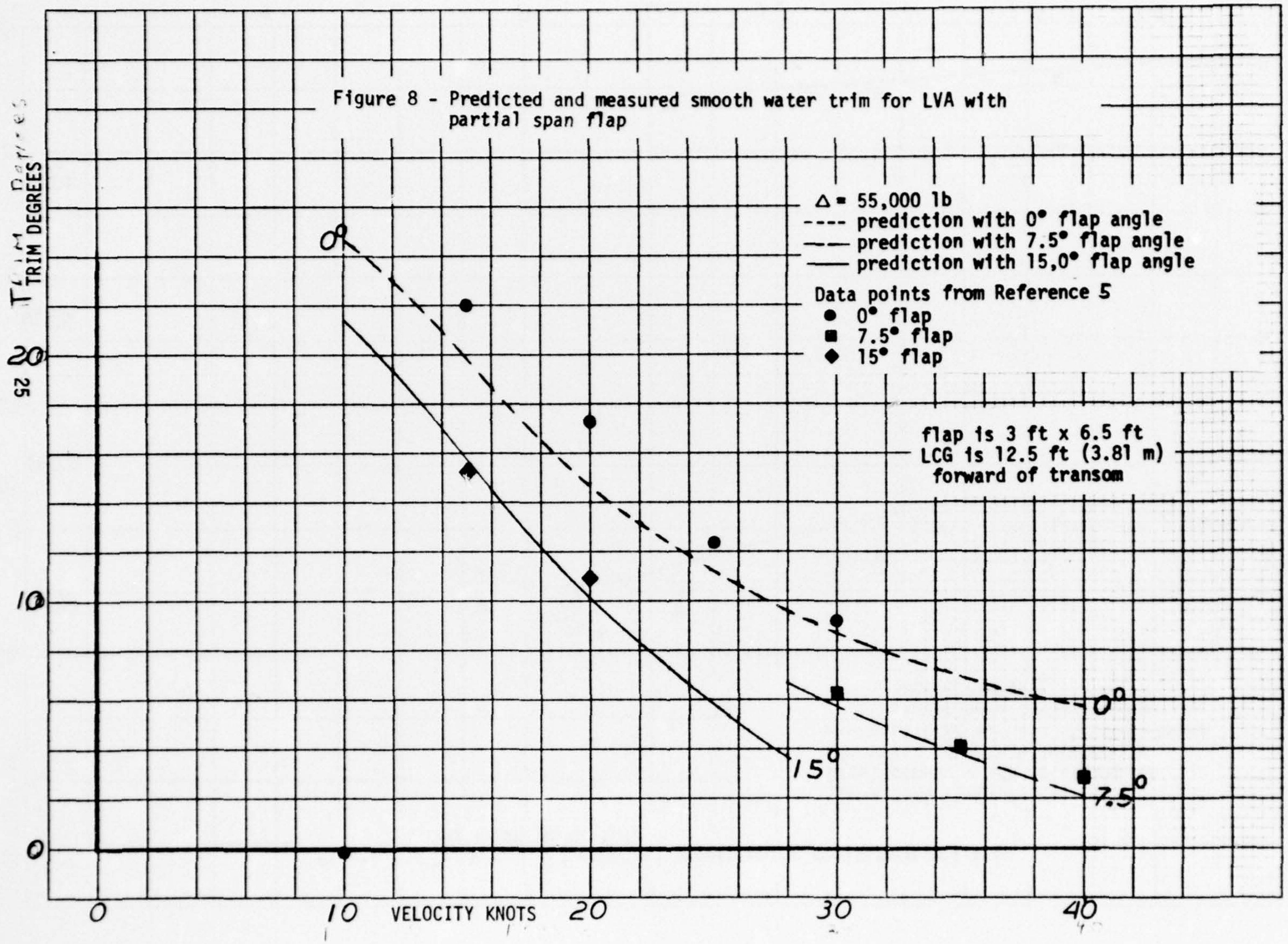


Figure 8 - Predicted and measured smooth water trim for LVA with partial span flap

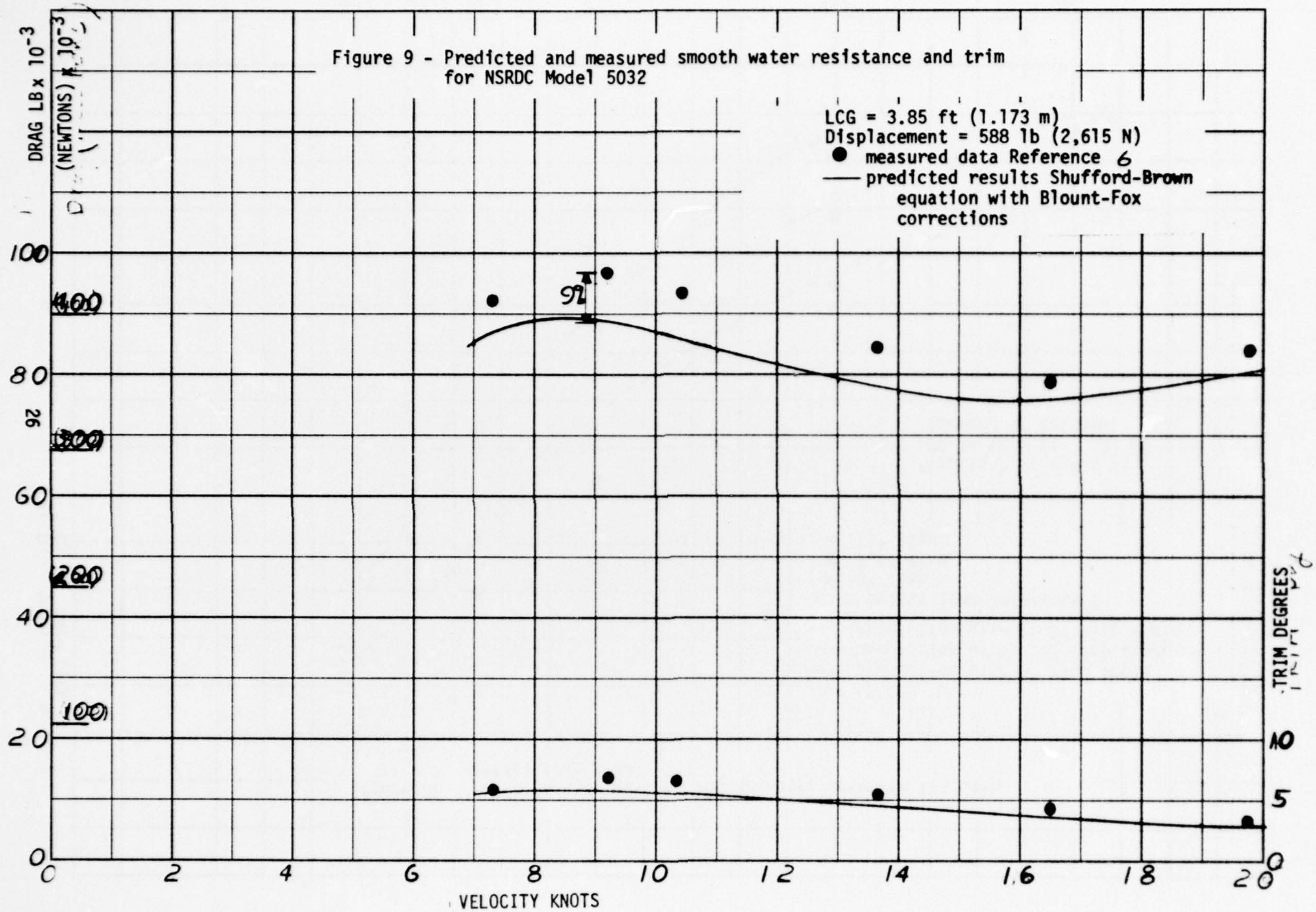


Figure 9 - Predicted and measured smooth water resistance and trim for NSRDC Model 5032

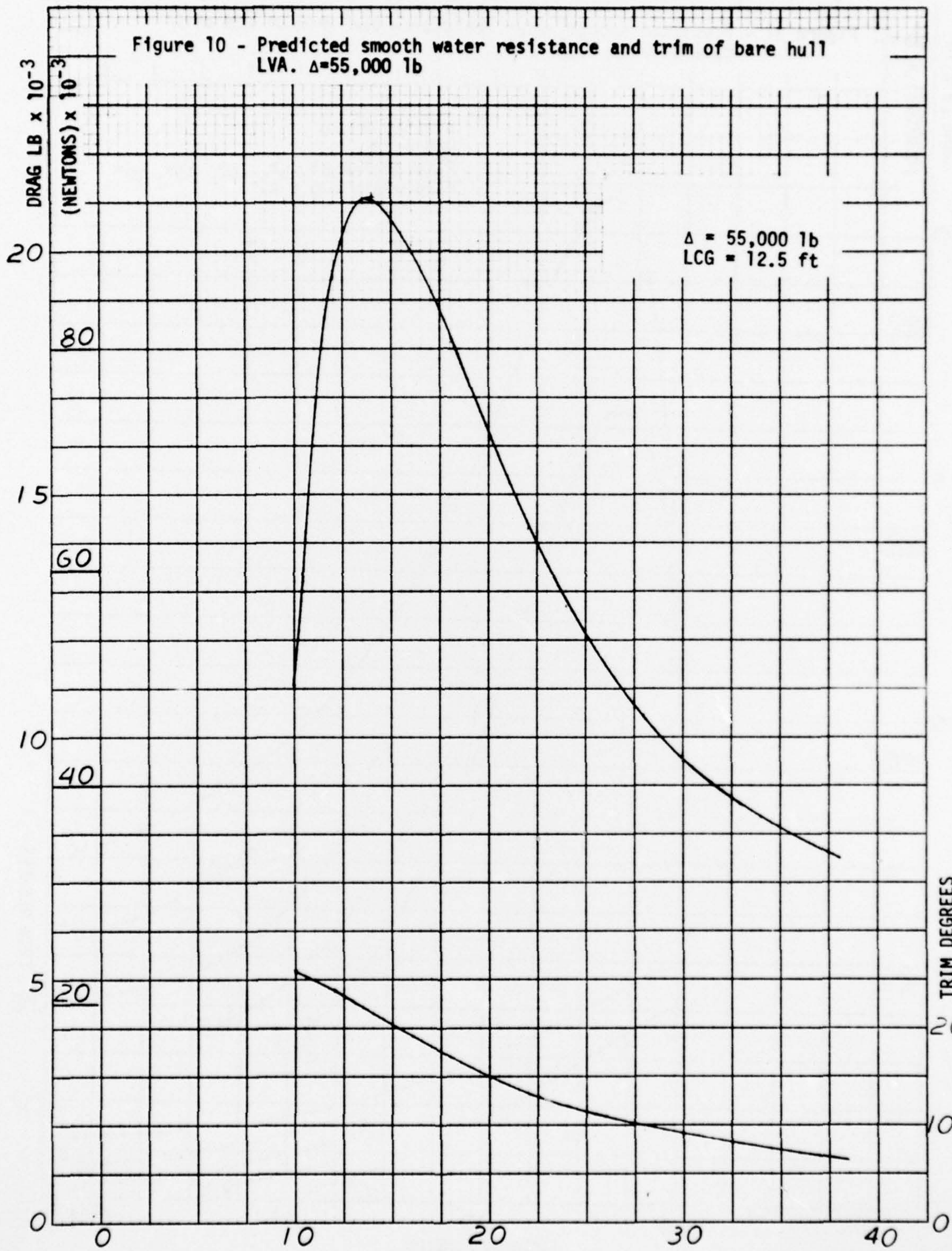
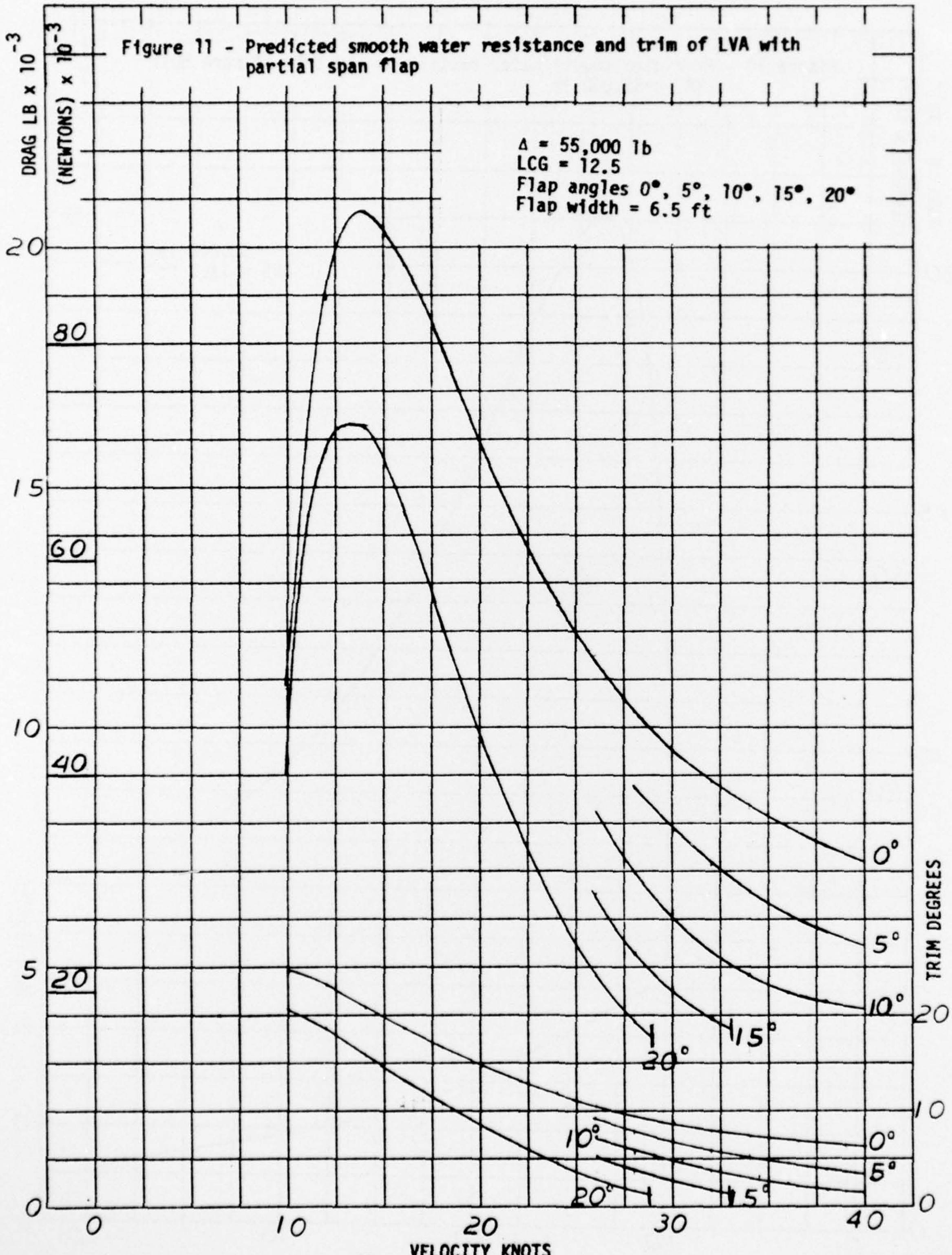


Figure 10 - Predicted smooth water resistance and trim of bare hull LVA. Δ=55,000 lb
Δ = 55,000 lb
LCG = 12.5 ft
DRAG LB x 10^{-3}
(NEWTONS) x 10^{-3}
TRIM DEGREES
VELOCITY KNOTS
0
5
10
15
20
20
40
60
80
0
10
20
30
40
0
10
20

Figure 11 - Predicted smooth water resistance and trim of LVA with partial span flap



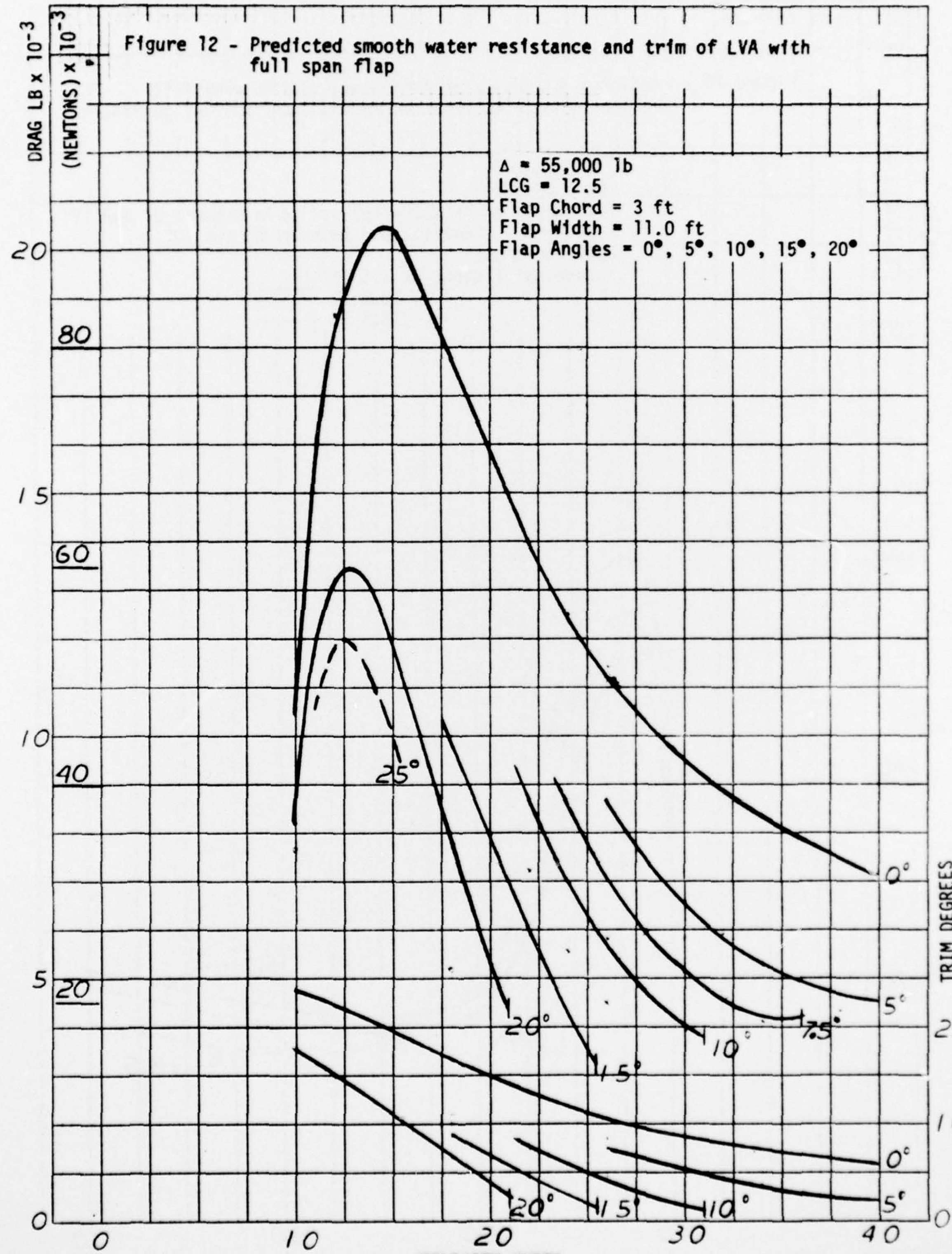


Figure 12 - Predicted smooth water resistance and trim of LVA with full span flap

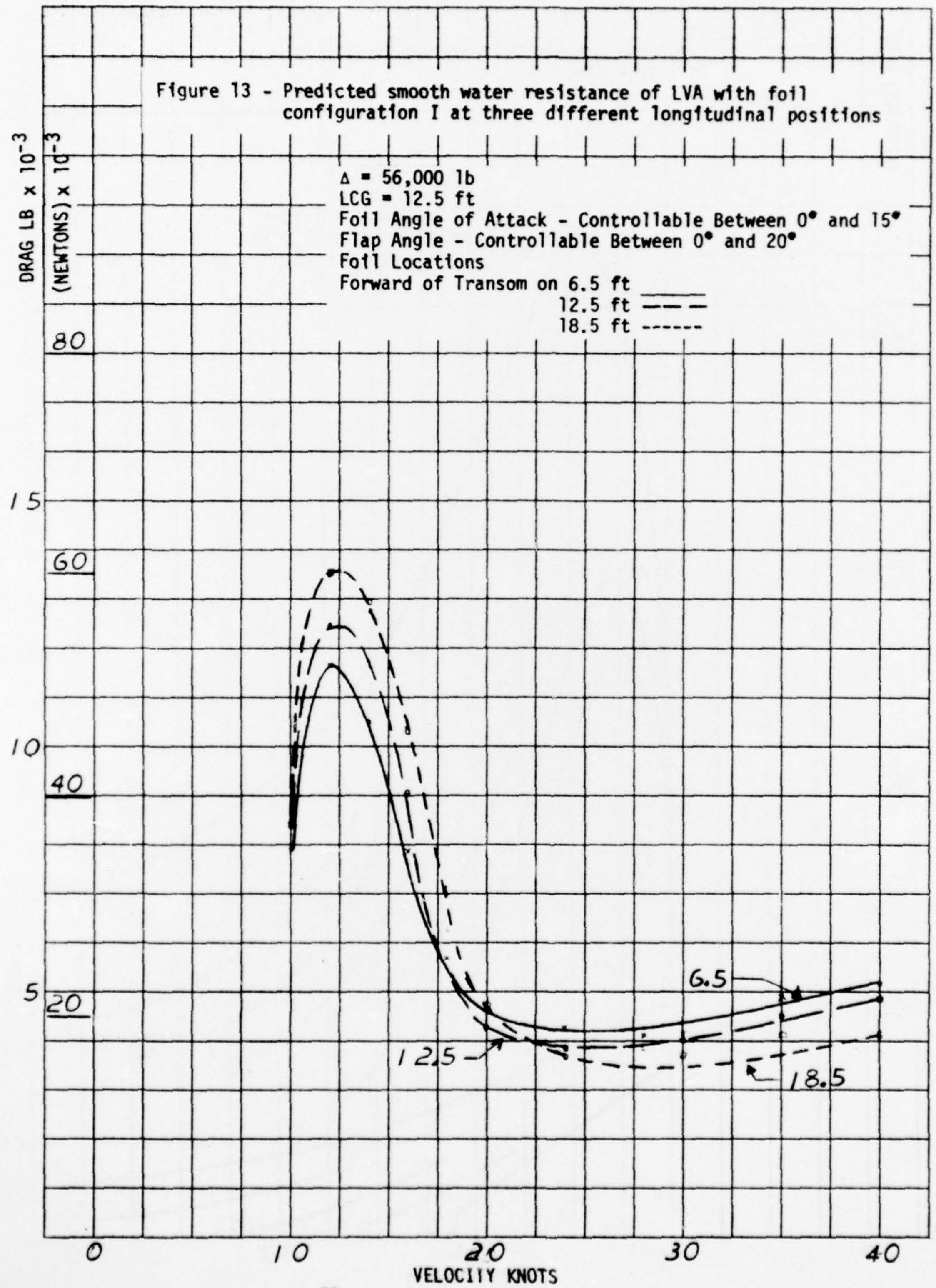


Figure 13 - Predicted smooth water resistance of LVA with foil configuration I at three different longitudinal positions

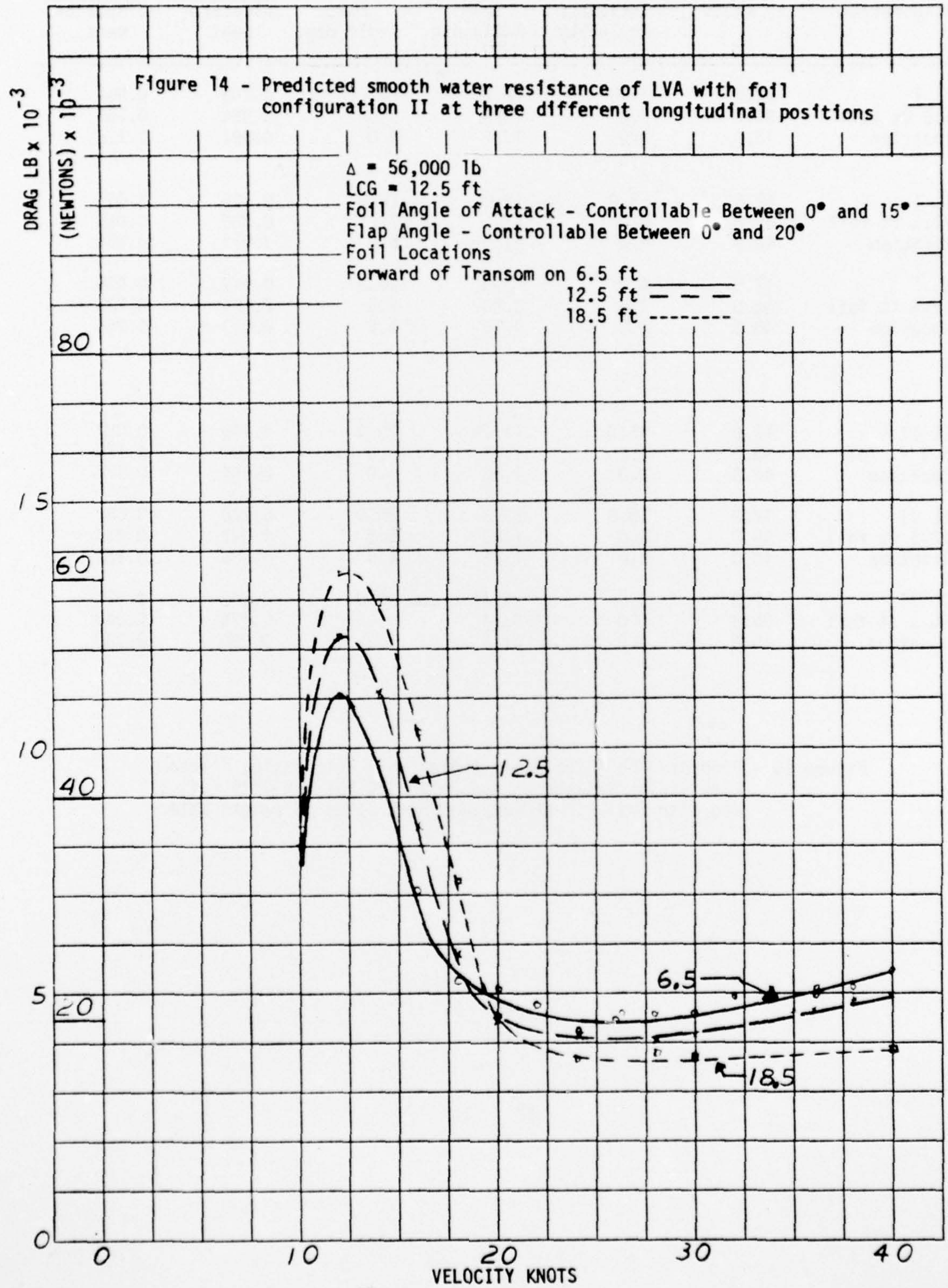
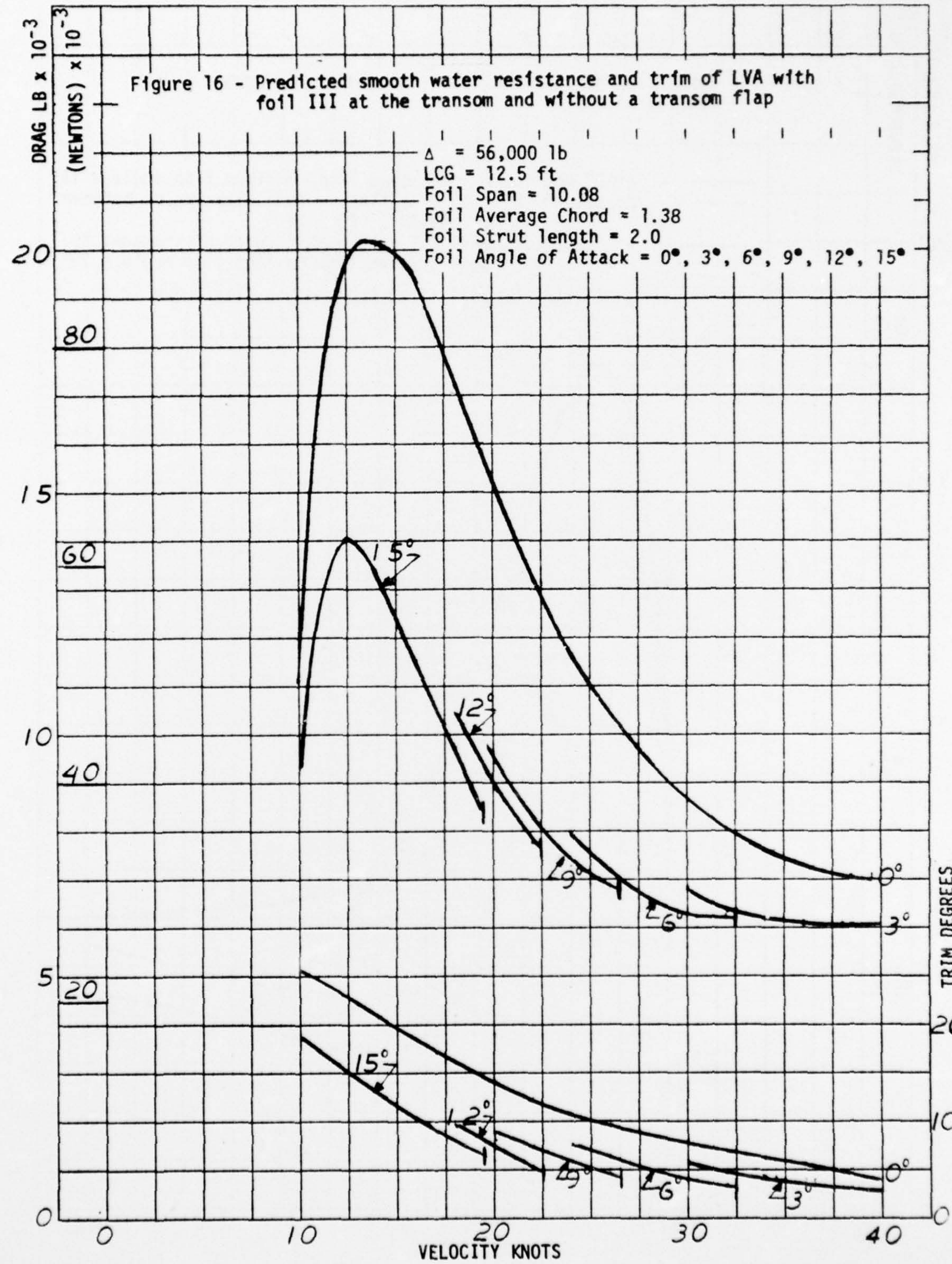


Figure 14 - Predicted smooth water resistance of LVA with foil configuration II at three different longitudinal positions

Configuration	Speed Knots	Foil Incidence Angle deg.	Hull Trim Angle deg.	Transom Flap Angle deg.	Resistance / Displacement	Foil Lift / Displacement
FOIL I	12.0	15.0	12.7	20.0	0.208	0.064
6.5 ft foil	35.0	3.0	1.98	5.0	0.086	0.163
location	40.0	1.0	1.74	4.0	0.091	0.128
FOIL I	12.0	15.0	13.9	20.0	0.225	0.064
12.5 ft foil	35.0	0.0	1.1	7.5°	0.080	0.065
location	40.0	4.0	0.70	5.0	0.073	0.256
FOIL I	12.0	6.0	18.0	20.0	0.242	0.030
18.5 ft foil	35.0	2.0	0.83	7.5	0.074	0.130
location	40.0	4.0	0.70	5.0	0.073	0.255
FOIL II	12.0	15.0	11.75	20.0	0.196	0.087
6.5 ft foil	35.0	2.0	1.88	5.0	0.087	0.175
location	40.0	2.0	1.82	3.0	0.097	0.176
FOIL II	12.0	15.0	13.5	20.0	0.220	0.087
12.5 ft foil	35.0	3.0	1.89	5.0	0.082	0.215
location	40.0	2.0	1.35	4.0	0.088	0.224
FOIL II	12.0	3.0	15.49	20.0	0.242	0.024
18.5 ft foil	35.0	4.0	2.24	5.0	0.075	0.248
location	40.0	4.0	0.35	5.0	0.068	0.330

Figure 15 - Predicted Foil Incidence Angle, Hull Trim Angle, Transom Flap Angle, Resistance and Foil Lift for LVA with Foil I and with Foil II at Hump and High Speed in Smooth Water



DRAG LB x 10^{-3}
(NEWTONS) x 10^{-3}
Figure 16 - Predicted smooth water resistance and trim of LVA with foil III at the transom and without a transom flap
Δ = 56,000 lb
LCG = 12.5 ft
Foil Span = 10.08
Foil Average Chord = 1.38
Foil Strut length = 2.0
Foil Angle of Attack = 0°, 3°, 6°, 9°, 12°, 15°
20
80
15
60
10
40
5
20
0
15°
12°
9°
6°
3°
0°
TRIM DEGREES
20
10
0
0
10
20
30
40
VELOCITY KNOTS

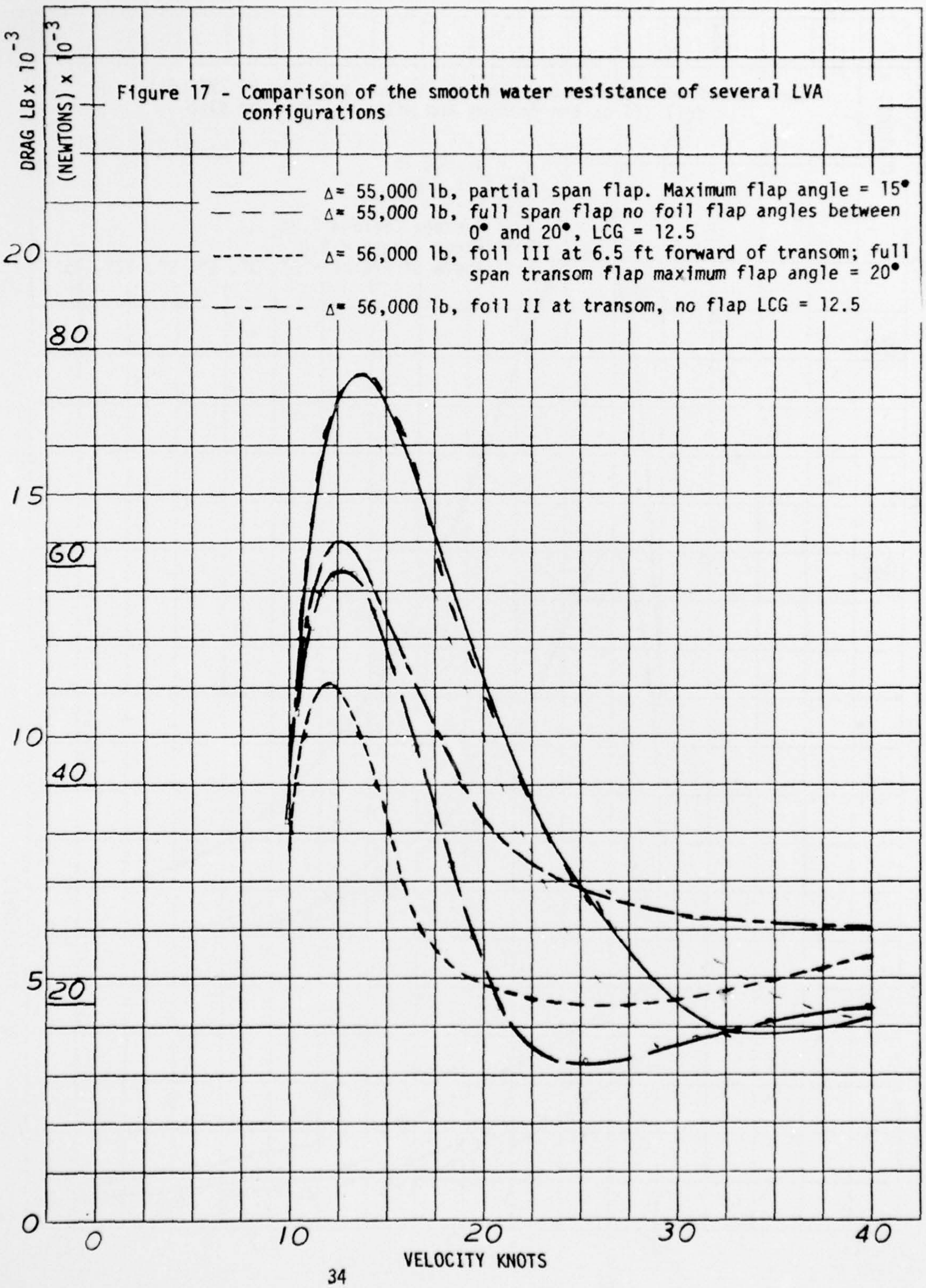


Figure 17 - Comparison of the smooth water resistance of several LVA configurations

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